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SYNTHESIS OF MINERALS USING ALTERNATIVE ENERGY SOURCES

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A technology for the synthesis of synthetic minerals (using the example of spinels) using a low-temperature plasma flame is developed. The diagnostic properties of spinels are identified.

The use of alternative energy sources, in particular, low-temperate plasmas makes it possible to produce competitive products by increasing the yield of synthesized minerals and lowering their production cost, compared to the traditional technologies, and to improve the environmental safety in the production of synthetic minerals by decreasing the effect of factors polluting the ambient environment and by using argon as the plasma-forming gas.

The interest in using plasma for synthesizing minerals continues to grow. Thus, in the synthesis of minerals and glasses using the improved Verneuil method, the gas flame is replaced by a plasma flame [1 – 3]. Lately a number of studies were dedicated to the synthesis in low-temperature plasma of such minerals as ruby, sapphire, yttrium-aluminum garnet, and amethyst [4 – 6].

The synthesis of pure crystalline materials using plasma is also performed by treating a briquetted batch by a low-temperature plasma flame. In subsequent treatment of the melt by regulating the distance from the plasma flame nozzle to the surface of the treated mixture, the melt is brought to a homogeneous state. The technique of melting under constant mixing provides a homogeneous melt and then, mixing the melt with the plasma-forming gas current, one can obtain a homogeneous product corresponding to a prescribed stoichiometric ratio. This significantly decreases stresses in crystallized products and contributes to a higher yield of the target product (RF patent No. 2104942).

However, this method of synthesizing minerals has a substantial drawback. In the course of plasma melting of batch briquettes, some batch components may get blown away from the crucible by the plasma-forming gas.

A technology of synthesis of minerals (using the example of spinels) has been developed using high-melting oxides and alternative energy sources. Since Al_2O_3 in the synthesis of spinel may combine with MgO in proportions different from stoichiometric requirements without a modification of the crystal structure (from $MgO \cdot Al_2O_3$ to $MgO \cdot 5Al_2O_3$), in our study we synthesized spinels of the most common composition: $MgO \cdot Al_2O_3$. Accordingly, we studied compositions based on Al_2O_3 and MgO. The colorant component in the synthesis of minerals was Fe_2O_3.

The initial materials were sulfates and sulfur oxides commonly used in the production of synthesized minerals. Aluminum oxide was synthesized from ammonia alum $NH_4Al(SO_4)_2 \cdot 12H_2O$ (GOST 4238–77), and magnesium oxide was synthesized from magnesium sulfate $MgSO_4$ (GOST 4348–78); Fe_2O_3 met the requirements of GOST 4173–77. The thermal treatment of alum produced a powder of dispersion 0.05 – 0.15 μm. The powders obtained for the synthesis of minerals were moistened to 9 – 10% and screened through a sieve with 10,000 cells/cm^2. As a result, we obtained particle agglomerates of size 50 – 80 μm suitable for plasma synthesis of minerals.

Calculated portions of required components were proportioned on an analytical scale with an accuracy up to 0.01 g and mixed to a homogeneous state in a porcelain ball mill with uralite balls. The batch composition used for the synthesis of spinel contained 72.9% Al_2O_3 and 27.1% MgO. The colorant pigment was 0.12% (above 100%) Fe_2O_3.

For the synthesis of spinel we chose a UPU-8M plasma gun with a GN-5R plasma burner. The plasma gun has the following parameters: working voltage 30 – 32 V, strength of current 450 A. The plasma-forming gas was argon, and its flow rate was 0.0142 g/sec under a pressure of 2.5 MPa.

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The process of synthesis of spinel included the following main operations: loading the batch into the powder feeder of the UPU-8M plasma gun, feeding the batch by an argon flow to the plasma burner GN-5R, melting the batch in the plasma burner, feeding melt drops via the waste plasma-forming gas into the crucible containing the seeds, crystallizing the melt in the crucible, and annealing the target product in a furnace.

The average temperature of the plasma jet at the burner nozzle exit was determined based on the enthalpy of the plasma-forming gas. The enthalpy of the plasma flame in the experiment was $(2.5 – 3.5) \times 10^4$ J/kg. When argon was used as the plasma-forming gas, the flame temperature reached 13,000 – 15,000 K and in using nitrogen it was only 5500 – 6500 K. Consequently, argon is the more efficient plasma-forming gas for melting high-melting metal oxides.

The practice of producing synthesized minerals demonstrated that the main criteria for selecting a production method is the crystal growth rate and the yield of the finite products; furthermore, the main limitation on the target product is its admissible residual stress value, which should not exceed 3 MPa.

The crystal growth rate depends on the plasma gun power and the flow rate of the plasma-forming gas. It is found that as the plasma gun power grows, the crystal growth rates increases up to 3 mm/min for an argon flow rate of 2.5 m^3/h. Increasing the argon flow rate to 3 m^3/h and the plasma gun power to 15 kW, the crystal growth rate decreases to 2.2 mm/min, and with a plasma gun power of 6 kW and a flow rate of the plasma-forming gas of 3.0 m^3/h the crystal growth rate is equal to 0.9 mm/min.

The optimum conditions of synthesis include a flow rate of the plasma-forming gas equal to 2.5 m^3/h and a plasma gun power of 9 kW. The crystal growth rate under the specified parameters is 2.8 mm/min and the anode and cathode of the plasma burner are not subjected to intense wear. As the gas flow rate decrease to 2 m^3/h, the nozzle is soon worn, which increases the production cost involved in repairs of the plasma burner. As the plasma-forming gas grows to 3 m^3/h, the plasma temperature sharply decreases, which decreases the rate of crystal growth to 0.8 – 1.5 mm/min.

Argon plasma has weakly reducing properties [7]. Therefore, variable-valence oxides become reduced in argon plasma. It is established that as the plasma gun power grows from 6 to 15 kW, Fe_2O_3 is reduced to FeO. Its is known that Fe_2O_3 imparts a green color to spinel, whereas FeO imparts light blue and cornflower-blue shades [7]. Therefore, the color of spinels produced under different parameters of plasma gun operation varies from green to light blue shades.

TABLE 1

Parameter*	Spinel		
	natural	synthesis in low-temperature plasma flame	synthesized by other methods
Light refraction	1.720 – 1.750** 1.712 – 1.719***	1.723 – 1.726	1.722 – 1.730
Density, kg/m^3	3580 – 3600	3591 – 3594	3590 – 3640
Microhardness, GPa	–	18.08	16.04 – 17.85
Cleavage	Imperfect	Perfect	Perfect
Stress, MPa	–	2.5	2.0 – 3.0

* In all cases Mohs hardness was 8, spinel was semitransparent, the line color was white, the luster glassy, and the fracture conchoidal.

** According to domestic researchers [8].

*** According to foreign researchers [9].

The diagnostic properties have been determined (Table 1) to identify the synthesized spinel.

It follows from the data in Table 1 that the properties of spinel synthesized in low-temperature plasma are not inferior to the properties of natural mineral or samples synthesized by other methods.

The developed technology is recommended for wide industrial application.

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